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Sensitivity of Physical Properties of Asphalt Concrete to the Change in Binder Content

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ABSTRACT

The variation of asphalt binder content from that of the job mix formula usually influences the required physical properties of asphalt concrete mixture. In the present investigation, asphalt concrete mixtures for wearing course are prepared at ± 0.5 % of the optimum binder content. Asphalt concrete slab samples were prepared using roller compaction. Beam specimens were obtained from the slab samples and tested for viscoelastic properties after practicing long term ageing and moisture damage. The deformation and flexural stiffness were evaluated with the aid of four-points bending beam test at 20 ºC environment and under constant micro strain level of 750. It was noticed that higher flexural stiffness could be detected for aged or moisture damaged specimens when compared with the control mixtures. It was concluded that the physical properties of asphalt concrete in terms of stiffness, and deformation is greatly sensitive to the variation in binder content. It was recommended that a stringent control of binder content should be implemented in the field to enhance the physical properties of asphalt concrete throughout its service life.

Keywords: Asphalt binder, Ageing, Flexure, Sensitivity, Deformation

1. INTRODUCTION

Varma et al., 2017 investigated the fatigue life of asphalt concrete mixtures using the four-point bending test. Two sets of asphalt concrete specimens were subjected to repeat strain-controlled sinusoidal loading at 20°C and 10 Hz frequency. The corresponding strain and stress data were collected at 1/1000 second interval. Data were implemented to evaluate the viscoelastic properties of asphalt concrete. A linear viscoelastic model was obtained. The fatigue properties were evaluated of asphalt concrete specimens by Pasetto and Baldo, 2017 in strain and stress control modes. The fatigue analysis was based on the internal damage produced within the asphalt concretes. The damage curves, as expressed in terms of the ratio of energy change, for both the stress and strain control modes, were elaborated and statistically analysed to verify the fatigue analysis of asphalt concrete. Sarsam, 2016 assessed the variations in the fatigue resistance of asphalt concrete mixtures. Beam

specimens were tested using the dynamic four-point flexure bending beam test in controlled strain mode. The deformation per load cycle was monitored through the changes in the behaviour of the mixture and through the damage accumulation. The impact of strain level, asphalt content, and testing temperature on permanent deformation was discussed and compared. Rondón-Quintana et al., 2021 stated that the calibration difficulty of the fatigue in asphalt mixtures models exists since the mathematical equations must be in capacity of considering that fatigue resistance of asphalt mixtures depends on the type of load (haversine or sinusoidal), the rest periods to which laboratory samples are subjected, and load mode (strain-controlled or stress-controlled). Additionally, variations with stiffness, volumetric composition, the geometry of samples and environmental conditions can affect mix durability. It was concluded that if these physical parameters are not considered, the mathematical equations will lose its reliability. Moreno-Navarro and Rubio-Gámez, 2016 revealed that fatigue cracking is considered as one of the main distresses which is responsible for the decline in the service life of asphalt concrete pavements. The fatigue phenomena are important for enhancing the durability of the pavement. It was concluded that the influence that permanent deformations can exert on the mechanical response of materials and the reversible phenomena of the damage during the development of fatigue processes should be assessed. Bessa et al., 2019 addressed that predicting asphalt pavements fatigue performance in relation to the main distresses can be monitored through laboratory characterisation and field evaluation. Various approaches may be implemented to determine what failure criterion to be considered, what testing conditions to be used, and which specimens' geometry to be produced. Some of the most common tests are diametral compression, the four-point bending beam, and the push-pull tests. Racanel and Burlacu, 2013 addressed that the asphalt binder gives an asphalt pavement waterproofing property, supports its flexibility, and binds the aggregate together. However, the binder content is a key mixture design parameter. Zou et al., 2019 stated that for a viscoelastic material, such as the asphalt concrete mixture, the external work applied to the material is consumed in part by inducing cracking on the surface and in part by inducing flow deformation. The binder content plays a major part in such behavior. Mandula and Olexa, 2017 assessed asphalt mixture problems which are caused by its inner properties and the behavior of material under dynamical loading. The phase angle was also studied as an indicator of viscoelastic behavior. It was stated that phase angle observation is important for better understanding of structural material behavior. It was observed that the phase angle value became stabilized after one third of the test duration while strong increase in the phase angle started slightly before failure point. It was concluded that sudden increase in the phase angle is one of the indicators of material lifespan ending. Carmo et al., 2021 analyze the structural sensitivity of a flexible pavement, which exhibits variations in its mechanical properties due to the asphalt binder content. A variation of ±0.5% within the optimum asphalt binder contents was used as service tolerance during the asphalt mixture manufacturing process. The indirect tensile strength and the resilient modulus of the mixtures were used for the structure analysis. The results show that the variations in the asphalt binder content influence the mechanical properties and corresponding structural responses of the investigated pavement. Omranian et al., 2020 assessed the influence of short-term ageing process on the volumetric properties and compactibility of asphalt concrete. Three different binders were utilized to prepare asphalt concrete mixtures. Volumetric properties and compactibility are considered as dependent variable, while ageing duration and ageing temperature are recognized as an independent variable. The findings revealed that there is a significant impact of ageing temperature and duration on compactibility, air voids, voids in mineral aggregate, and voids filled with asphalt. Rahmani et al., 2017 revealed that the stiffness modulus of asphalt concrete may increase by four folds after the ageing process based on the binder type. However, this may cause the mixture to become stiffer and brittle so that it will be susceptible to fatigue cracking at low temperatures and disintegration. The behavior of asphalt concrete depends mainly on the rheological behavior of the asphalt binder as reported by Shafabakhsh et al., 2021. Asphalt binder behaves in a visco-elastic manner, therefore the behavior of asphalt concrete mixtures changes with the change in environment temperature. The asphalt binder exhibits visco elasto-plastic behavior at high temperature while it exhibits elastic behavior at low temperatures. Al-Khateeb and Alqudahaims, 2018 assessed the impact of laboratory ageing on the fatigue-life performance of asphalt concrete mixtures. The mixtures were subjected to short and long-term ageing then tested for fatigue using the repeated indirect tensile test at various initial strain levels. It was observed that the short-term ageing led to an increase in fatigue-life. Findings also showed that the fatigue-life of asphalt concrete increased as the testing temperature increase. Sarsam, 2016 investigated the influence of ageing process on the flexural stiffness of asphalt concrete specimens through the fatigue process. It was detected that the stiffness is susceptible to ageing while the increase in micro strain level leads to a remarkable reduction in initial and failure stiffness's. It was concluded that the stiffness is susceptible to the asphalt content, higher binder content exhibit a negative impact on the stiffness.

The aim of the present investigation is to assess the sensitivity of the viscoelastic properties of asphalt concrete mixtures to the variation in asphalt cement content. The assessment will be conducted based on dynamic flexural behavior throughout the fatigue life of the mixture. The phase angle, deformation, dissipated energy, and the flexural stiffness will be assessed through the fatigue process.

2. MATERIALS AND METHODS

The materials implemented in the present investigation are locally available and are widely used in asphalt pavement construction.

Asphalt Cement

Asphalt cement of penetration grad 40-50 was implemented in this work. It was obtained from AL-Nasiriya Refinery. The physical properties of asphalt binder are listed in Table 1.

Table 1. Physical Properties of Asphalt Cement Binder

Physical properties	ASTM, 2016 Designation	Asphalt cement	SCRB, 2003
Penetration	D5-06	42	40-50
Softening Point °C	D36-95	49	-
Ductility Cm	D113-99	100+	>100
Specific Gravity	D70	1.04	-
Flash Point °C	D92-05	269	>232
Retained Penetration of Residue	D5-06	33	<55
Loss in weight (163°C, 50g,5h) %	D-1754	0.175	---
Ductility of Residue	D113-99	130 cm	>25

Fine and Coarse Aggregates

Crushed coarse aggregates, (retained on sieve No. 4) was obtained from AL-Ukhaider quarry. Crushed and natural sand mixture was implemented as fine aggregate (passing sieve No.4 and retained on sieve No.200). It was obtained from the same source. The aggregates were washed, then air dried and separated into different sizes by sieving. The physical properties of aggregates are demonstrated in Table 2.

Table 2. The Physical Properties of Coarse and Fine Aggregate as per ASTM, 2016

Property	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity (ASTM C 127 and C 128).	2.642	2.658
Percent Water Absorption (ASTM C 127 and C 128)	1.07	1.83
Percent Wear (Los-Angeles Abrasion) (ASTM C 131)	18 %	-

Mineral Filler

The mineral filler implemented in the present investigation is the limestone dust which was obtained from Karbala governorate. The filler passes sieve No.200 (0.075mm). The physical properties of the mineral filler are presented in Table 3.

Table 3. The Physical Properties of Mineral Filler

Property	Value
Bulk specific gravity	2.617
% Passing Sieve No.200	94

Selection of Aggregates Combined Gradation

The selected aggregates gradation in the present investigation follows SCRB, 2003 specification for dense graded wearing course pavement layer with 12.5 mm nominal maximum size of aggregates. Table 4 shows the selected aggregate gradation.

Table 4. Aggregates Gradation implemented for Wearing Course as per SCRB, 2003

Sieve size mm	Selected gradation	SCRB, 2003 Specifications
19	100	100
12.5	95	95-100
9.5	83	76-90
4.75	59	44-74

2.36	43	28-58
0.3	12	5-12
0.075	7	4-10

Preparation of Asphalt Concrete Mixture and Specimens

The fine and coarse aggregates were combined with mineral filler to meet the specified gradation for wearing course. The combined aggregates were then heated to 160 ºC before mixing with asphalt cement. The asphalt cement was heated to 150 ºC, then, the binder was added to the heated aggregate to the desired amount and mixed thoroughly by hand using a spatula for two minutes so that the aggregate particles are coated with the binder. The mixture was subjected to short-term ageing process for 4 hours at temperature of 135 ºC according to AASHTO R-30, 2002. The optimum asphalt content of 4.9% was implemented. The optimum binder percentage was determined based on Marshall Trial mixes using various asphalt percentages. Details of obtaining the optimum binder content could be found in Sarsam and Alwan, 2014. The short-term aged mixtures were casted in a slab mold of (40 x 30 x 6) cm and subjected to roller compaction to the target bulk density for each binder percentage according to EN12697-33, 2007. The applied static load was 5 kN while the number of load passes depended on the asphalt content in the mixture and was determined based on trial-and-error process. Details of the compaction process could be referred to Sarsam, 2005. The compaction temperature was maintained to 150 °C. Slab samples were left to cool overnight. Beam specimens of 50±2 mm high, 63±2 mm wide and 400 mm length were obtained from the compacted slab sample using the Diamond-saw. The total number of beam specimens obtained was twelve, while the number of casted slabs was three.

Long-term Ageing of Beam Specimens

Part of the beam specimens was subjected to oxidation ageing (long-term ageing), beams have been stored in an oven for five days (120 hours) at 85°C as per AASHTO R-30, 2002 procedure. Specimens were then withdrawn from the oven and stored in the testing chamber for two hours at the required testing temperature of 20°C for the fatigue test.

Conditioning of Beam Specimens for Moisture Damage

Another group of the beam specimens was subjected to moisture damage by conditioning the beams in water bath at 25º C for two hours, the air in the voids was evacuated using a compressor with a vacuum of 3.74 kPa applied for 10 minutes to obtain 80 % saturation. The asphalt concrete beam specimens were then placed in a deep freeze at (-18°C) for 16 hours. The frozen beam specimens were then moved to a water bath and stored for 24 hours at (60ºC). Then they were dried and placed in the testing chamber for two hours at 20º C before testing for fatigue life. The only deviation of this procedure from that described in AASHTO, 2002 is that the tested specimen is a beam and not a cylindrical specimen.

Repeated Flexural Bending Beam Test

The four-point repeated flexural bending beam test according to AASHTO T321, 2010 was implemented to identify the influence of additives on the fatigue life and flexural stiffness of asphalt concrete beam specimens at intermediate pavement operating temperature of 20 °C and under constant micro strain level of 750. During the flexural fatigue test, the beam is subjected to repeated four-point loading. The load frequency is usually set 5 Hz, and the deflection caused by the loading is measured at the center of the beam. The test was terminated when the beam has reached a 50 percent reduction in stiffness. A repeated sinusoidal (tension-compression) load is applied to the two inner clamps on the beam specimen with the outer clamps providing a reaction load. This setup produces a constant bending moment over the center portion of the beam (between the two inside clamps). Beams were subjected to a repeated load at a constant strain level. One constant Micro strain level of 750 was tried to simulate heavy traffic mode of loading in the field. Figure 1 exhibit the dynamic flexural bending beam test setup while Figure 2 shows part of the prepared asphalt concrete beam specimens.

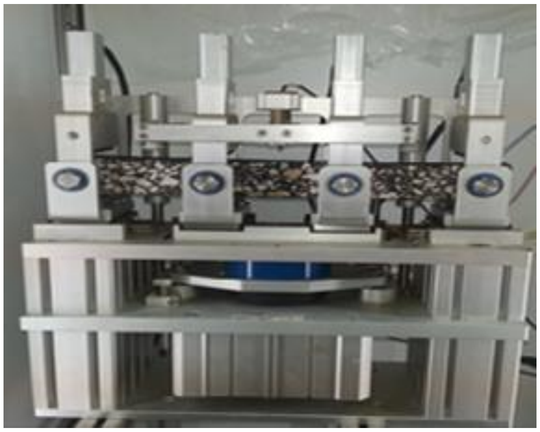

Figure 1. Dynamic flexural bending beam test

Figure 2. Part of the prepared Beam Specimens

3. RESULTS AND DISCUSSIONS

Influence of Binder Content on Flexural Stiffness

As demonstrated in Figure 3, the flexural stiffness decline as the repeated loading proceeds. The moisture damaged beam specimens exhibit lower flexural stiffness as compared with the control specimens regardless of the binder content. However, asphalt concrete prepared with high binder content exhibit higher flexural stiffness as compared with specimens prepared with lower binder content regardless of the moisture conditioning process. This may be attributed to the fact that higher binder content provides higher binder film thickness to resist the stripping after exposure to the moisture conditioning. Similar behavior was noticed by Racanel and Burlacu, 2013, as it was reported that the asphalt binder provides an asphalt pavement waterproofing property, supports its flexibility, and binds the aggregate together. The binder content is a key mixture design parameter. On the other hand, higher binder content exhibit longer fatigue life of asphalt concrete for both control and moisture damaged mixtures. The fatigue life for mixtures with high binder content was (400, and 133) % higher than that of lower binder content for control and moisture damaged mixtures respectively.

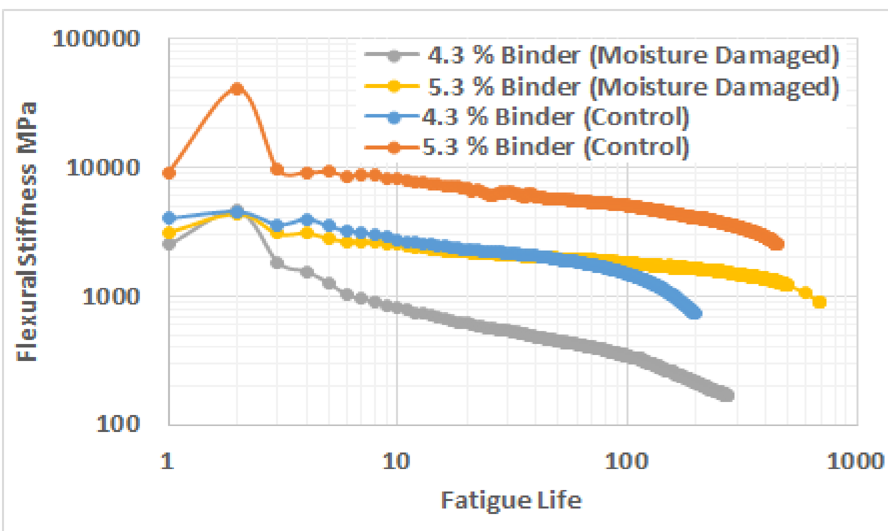

Figure 3. Influence of Binder Content and Moisture Damage on Flexural Stiffness

Figure 4 exhibit the influence of binder content and ageing process on the flexural stiffness of asphalt concrete mixture. The flexural stiffness in general decline through the fatigue life of the mixture for control and long term aged specimens. Higher binder content exhibits higher flexural stiffness for control and aged mixtures. On the other hand, the long term ageing process of asphalt concrete exhibits higher flexural stiffness as compared with the control mixture regardless of the binder content. The stiffness of asphalt concrete may increase by four folds after the ageing process based on the binder type as revealed by Rahmani et al., [12]. However, this may create a stiffer and brittle mixture and it will be susceptible to disintegration and fatigue cracking at low

temperatures. Aging process can stiffen the asphalt cement binder and negatively affects the viscosity, it makes the pavement more prone to various types of distress, such as raveling and cracking as reported by Tauste et al., 2018.The fatigue life for mixtures with high binder content was (166, and 275) % higher than that of lower binder content for control and long term aged mixtures respectively.

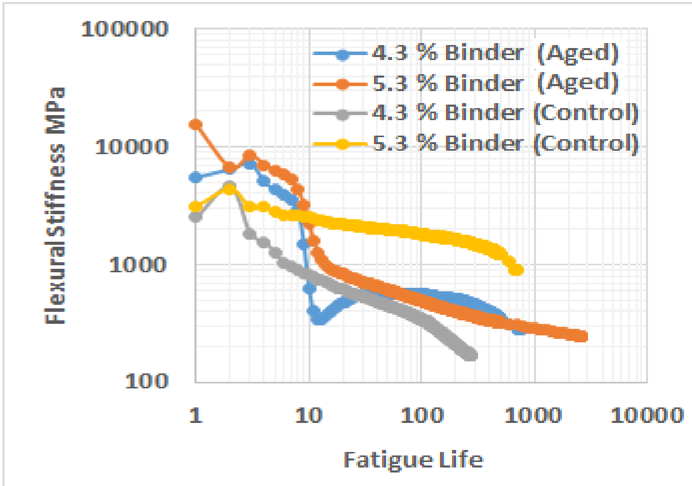

Figure 4. Influence of Binder Content and Ageing on Flexural Stiffness

Influence of Binder Content on Deformation

Figure 5 demonstrate the influence of asphalt binder content on the permanent deformation of asphalt concrete specimens through the fatigue process. Higher deformation could be detected for asphalt concrete specimens prepared with lower binder content for control and long term aged specimens. However, the long term aged mixture exhibit lower permanent deformation as compared with the control mixtures regardless of the binder content. Long term ageing exhibit positive impact on deformation since the binder gets stiffer after the ageing process. The aged specimens exhibit lower deformation by 20 % than the control specimens. Similar behavior was reported by Carmo et al., 2021.

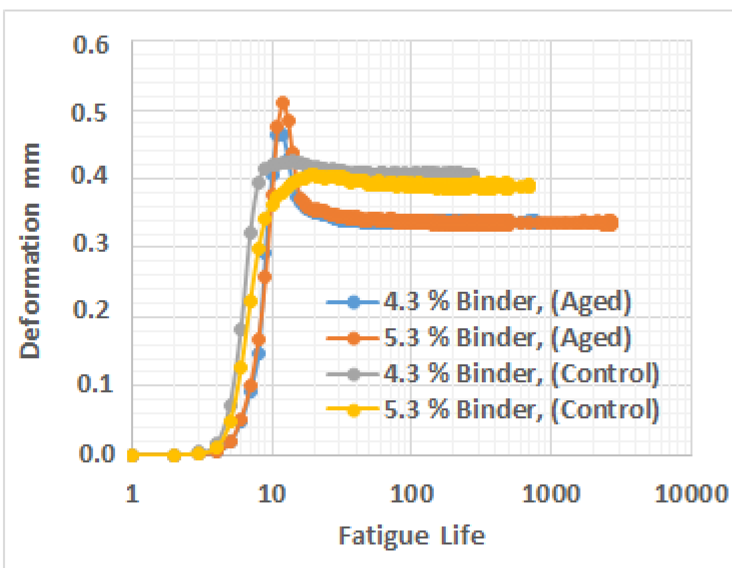

Figure 5. Influence of Binder Content and Ageing on Deformation

Figure 6 exhibit the influence of asphalt binder content on the deformation of asphalt concrete for control and moisture damaged asphalt concrete specimens. It can be detected that the asphalt concrete specimens after practicing moisture damage

exhibit higher permanent deformation as compared with the control mixtures. On the other hand, higher binder content shows lower deformation for control and moisture damaged specimens. This may be attributed to the stripping of asphalt binder which decreases the adhesion between the aggregate particles and the cohesion between the aggregate and the asphalt cement. Tauste et al., 2018 reported similar behavior.

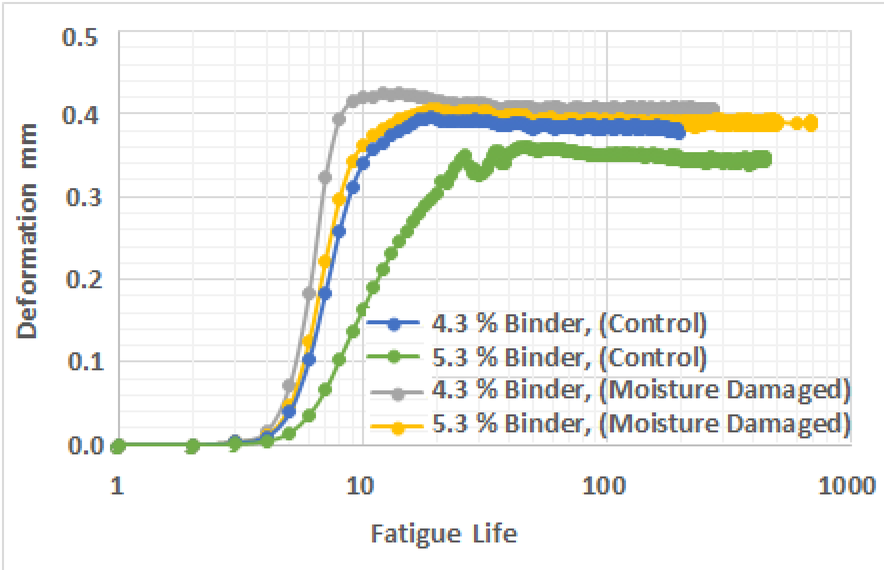

Figure 6. Influence of Binder Content and Moisture Damage on Deformation

4. CONCLUSIONS

Based on the limitation of the testing and the materials, the following conclusions may be addressed.

1. Asphalt concrete prepared with high binder content exhibit higher flexural stiffness as compared with specimens prepared with lower binder content regardless of the ageing or moisture conditioning process.
2. The high binder content for aged specimens exhibits lower deformation by 20 % than the control specimens, while the moisture damaged specimen exhibits higher deformation than the control specimens.
3. The physical properties (stiffness and deformation) of asphalt concrete are highly sensitive to the variation in asphalt cement binder content.

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Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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